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MEDICAL RESEARCH LABORATORY

U.S. Naval Submarine Base
New London

THE EFFECT OF CHANGING THE ILLUMINATION ON THE COLORS IN PSEUDO-ISOCHROMATIC PLATES

COLOR VISION REPORT NO. 5

Medical Research Laboratory Report No. 35

This report was prepared by
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SUMMARY

The effect of illumination in changing the relationships between colors is discussed. Particular reference to this change is made concerning color blinds and how their responses to pseudo-isochromatic tests will differ under different lighting conditions. Finally, the application of these conclusions to a particular plate in the present Navy test is shown.

Non-standard illumination has the following effects:

1. The intended relationships in the tests no longer hold.

2. The degree of stringency of the test is altered.

3. Under incandescent illumination the test becomes much easier for deuteranomalous observers, and less easy for protanopes.

PROBLEM

Color vision tests are frequently given in the Navy under incandescent illumination[1]. Pseudo-isochromatic tests are designed to be presented under average daylight illumination, and the use of a yellower illuminant changes the responses of color blinds to these tests. Deuteranopes tend to make many less errors under incandescent illumination than they do under standard daylight. Severely defective protanopes do not appear to be aided by warmer illumination, but mild protanopes do benefit[2]. This is an investigation of the reasons why changes in illumination lead to changes in response. This information is a prerequisite to intelligent interpretation of test results and to the creation of plates for diagnosis and selection.

METHOD

The investigation is in two parts. The first is a general study of pseudo-isochromatic plates, how they work, and how color-blinds see them. The second is an analysis of a specific plate in terms of the colors used, and how this plate follows the general principle of pseudo-isochromatic plates. This study indicates how a color changes with illumination, and thus why non-standard illumination leads to artifacts in test results.

DISCUSSION

Effect of illumination on hue. The very considerable effect that illumination has upon colors is not generally appreciated. The light from a 100-watt incandescent lamp is relatively much more red and yellow than standard daylight, and the former contains much less blue. This means that a blue colored surface reflects far less blue light when illuminated by a 100-watt lamp than when illuminated by daylight. This effect can hardly be overestimated. The

enclosed pair of color samples, red and purple (Plate I), are an
example of this point. The red under the blue light of daylight and
the purple under the yellow light of an incandescent look identical
if the specific illumination is not perceived.

As illumination shifts from daylight to 100-watt mazda,
colored surfaces undergo a change. They do not, however, change
all in the same way or to the same degree. In order to illustrate
this, a color graph may be drawn to a scale so that colors which
appear equally different are represented by equal linear distances
(uniform chromaticity scale diagram). Colors can be selected which
under standard daylight would be plotted as an approximate circle.
These colors would appear to be equally different from gray or
neutral. Then the position of these same colors under the 100-watt
mazda lamp can also be plotted for comparison. There is, as noted
before, a definite shift in the appearance of the colors as a result
of their illumination by the yellow light, and the circle becomes an
ellipse. This represents the fact that certain of the colors now appear
more confusable with each other and with gray. For example, blue
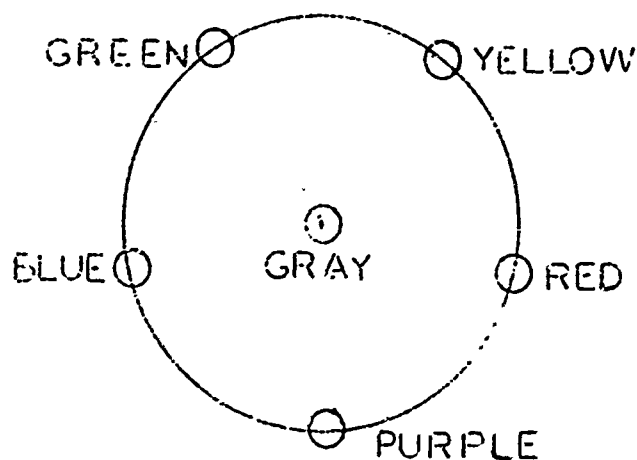and green look very much alike by artificial light. See Diagrams 1
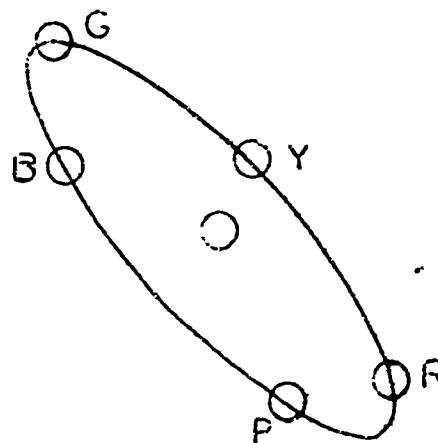and 2.

Diagram 1

Diagram 2

PLATE I

The RED under average daylight and the PURPLE
under 100-watt Mazda light are the same color.

This effect may be demonstrated by removing and folding
the black paper on a vertical central line to make a wedge so that
one side receives light from a daylight Macbeth or fluorescent
lamp while the other receives it from a Mazda. A black back-
ground aids in destroying the constancy effect, so that it may be
perceived that the colors are alike. The experiment is best per-
formed in a dark room or with the lamp well shielded so that
neither square of color receives light from the opposite lamp by
reflection. The two colors are standard Munsell R 5/8, P 4/10.
The ICI x-y coordinates for the R under standard daylight are 469
and 318, and for the P under 100-watt Mazda are 468 and 317,

This shift is accurately plotted out in Figure 1, using standard colors, and the radical change in the relationships is obvious. This discrepancy is perhaps unimportant in everyday life, but becomes highly significant in the testing of color vision by the use of pseudo-isochromatic plates. To understand this significance, it is necessary to discuss the principle underlying these plates.

Diagram 3. is a uniform chromaticity scale diagram (UCSD) for a color normal individual.

A color-anomalous person, however, does not see as many just noticeable steps between red and green as he does between blue and yellow. He even confuses red with blue-green. A case such as this is plotted in Diagram 4, where the only color sensations experienced are those of blue and yellow, where colors can be distinguished only if they contain different amounts of yellow and blue.
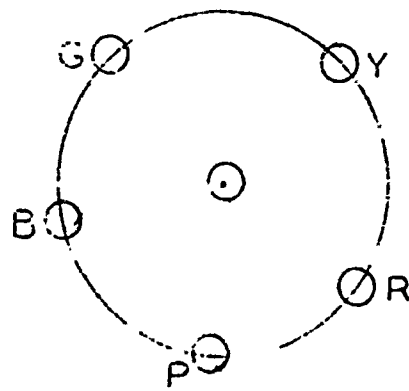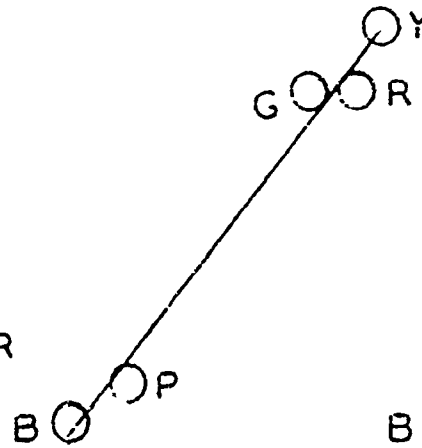

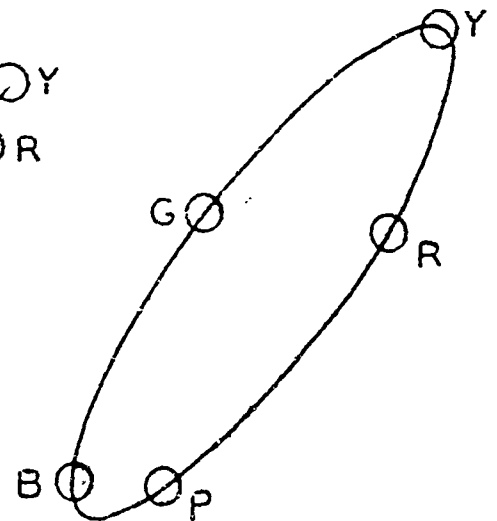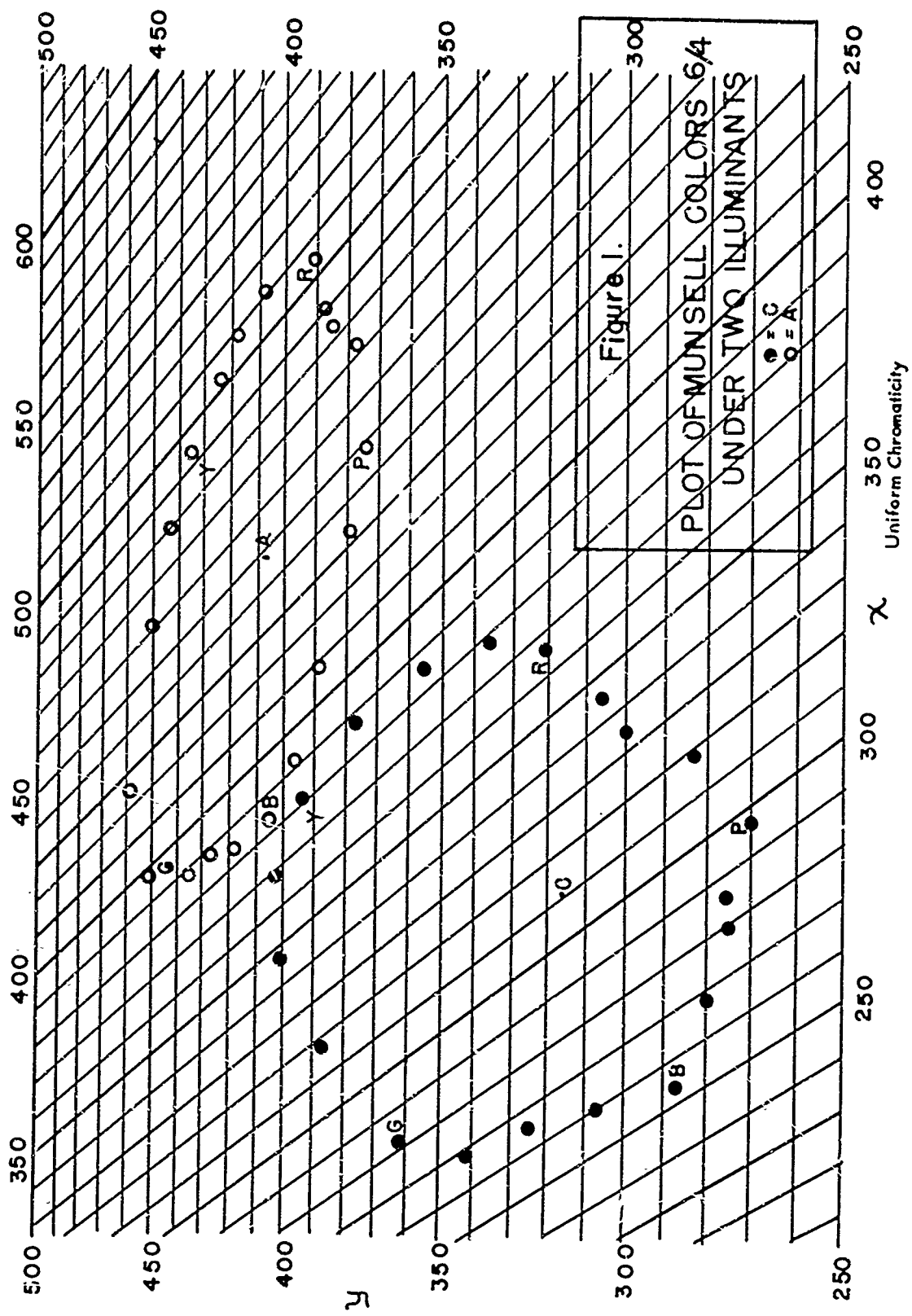Diagram 3   Diagram 4   Diagram 5

PLOT OF MUNSELL COLORS 6/4
UNDER TWO ILLUMINANTS

Figure 1.

● = C
○ = A

This extreme sort of case is relatively rare, however, and generally the reduction is of the nature shown in Diagram 5, where the difference between green and red is merely less than that between yellow and blue.

Pseudo-isochromatic tests are constructed so as to apply these facts in the following way: Some of the plates are so designed that a color-normal individual sees one number and a color-deficient individual sees another. Such plates are composed essentially of four colors, so located on the UCSD that they present one configuration to the normal eye and a different one to the color deficient. See Diagram 6.
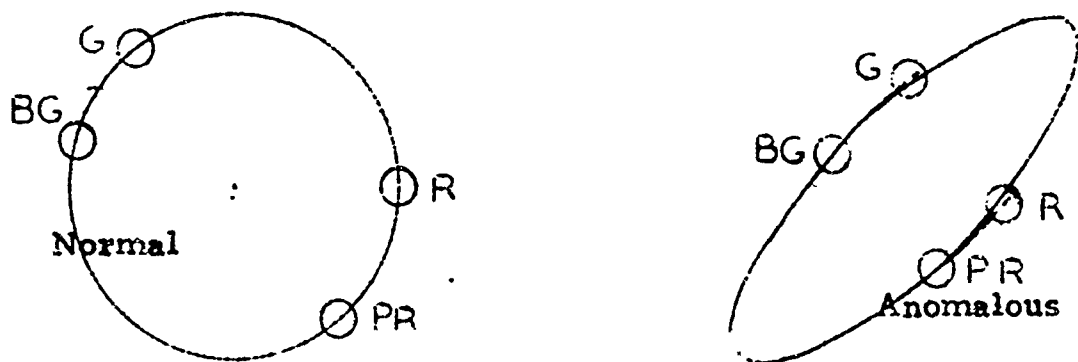

Diagram 6

To the color normal individual, a pattern appears, made up of dots of orange and purple-red on a background of green and blue-green; this is so because the red and purple-red look more like each other to him than they do like either of the background colors. . For the color deficient person, these relationships change. The red no longer looks more similar to the purple-red than to the green, since to the color-blind eye, the difference between red and green is less striking than that between varying amounts of blue. As a result, the grouping is reversed, and the color-anomalous subject picks out a pattern composed of purple-red and blue-green dots on a background of red and green. This pattern is not obvious, of course, to the normal eye.

This type of confusion plate is thus a positive indication
of color deficiency, and as such is very valuable. However, under
faulty illumination (all pseudo-isochromatic plates were intended
to be shown under daylight) it loses this value and becomes worse
than useless. Diagram 7 again shows four colors from a pseudo-
isochromatic diagram under standard daylight.

Diagram 8 shows the positions of these same colors as
they appear to the normal eye, under 100-watt mazda illumination.
For the normal, the effect of the plate is strongly reinforced by the
foreshortening of the difference (distance on the diagram) between
the colors which combine to make up the figure, and the exaggera-
tion of the difference between the figure and the background.

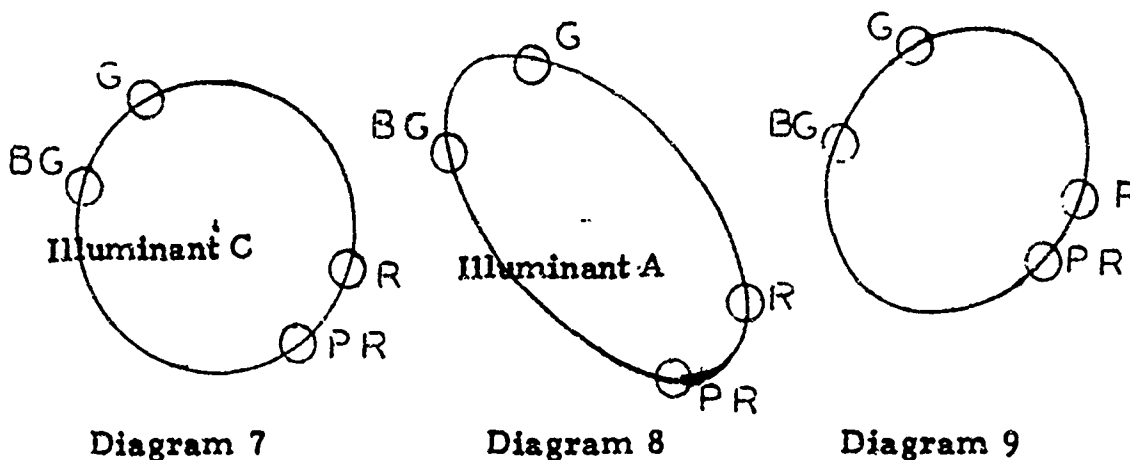Diagram 7   Diagram 8   Diagram 9

Diagram 9 illustrates the relationships in Diagram 8, as they appear
to a color-anomalous individual. Even though a shift in the appear-
ance of the colors does take place, the effect is not strong enough
to counteract the action of the yellow illumination, and consequent-
ly the so-called "normal" configuration is seen and reported by
color deficient observers.

The second effect of changing from standard daylight to 100-watt incandescent illumination is that two colors which are confused by color blinds may no longer look similar to them under different light. The two common types of color deficiency are deuteranomaly (green blindness), and protanomaly (red blindness). Deuteranopes tend to confuse red with green, and protanopes confuse red with blue-green. See Diagram 10.
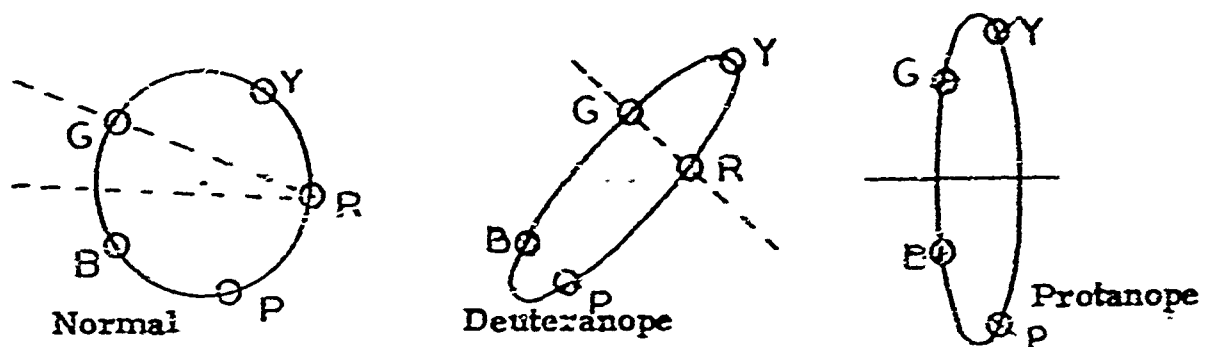

Diagram 10

Pseudo-isochromatic plates are usually designed to be equally difficult for both types of anomalous individuals. Plates designed according to this assumption and administered under the light for which they were designed are equally effective for both types of anomalous, but not maximally effective for either. When the illumination on the plates is changed, there is not only a distortion in the differences between colors, but also a shift in the relationships as seen by the two types of color blind. For example, under 100-watt Mazda illumination, the circle shifts, and the relative positions of the confused colors move so that they would look more similar to the protanope and less so to the deuteranope. This is illustrated by the dotted line in the diagram which lies halfway between the deuteranomalous and protanomalous lines of maximum confusion, under Illuminant C (Diagram 11).
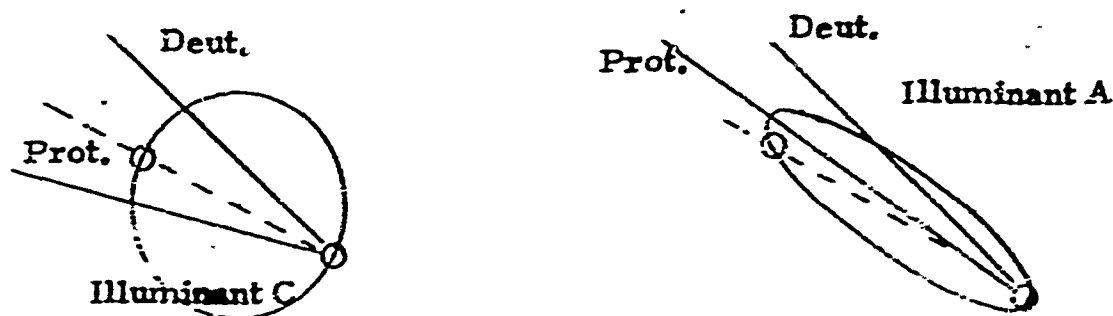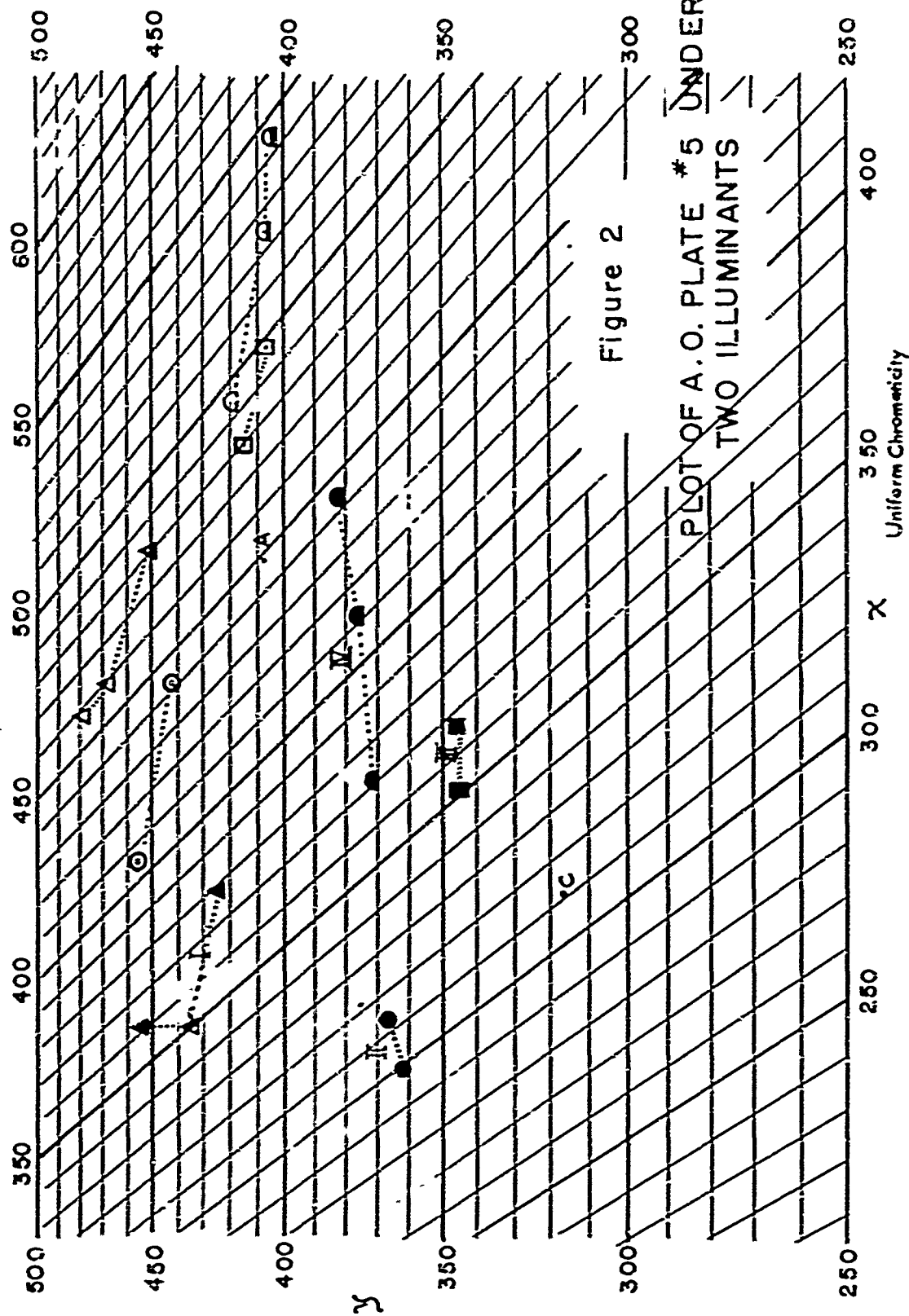
Diagram 11

This will mean that the plate made up of these colors will become much easier for the deuteranope for two reasons: first, the change from circularity is an aid and secondly, the shift in the colors in the plates tends to make the colors which the green blind confused under the standard light no longer alike to him. The protanope, while aided by the distortion, is not benefited by the shift in the relations of the colors; if he is only mildly protanomalous he will be benefited by the distortion of the circle, but if he has a more severe protanomaly the distortion will not be strong enough to counteract the effect of the anomaly.

ANALYSIS OF A SPECIFIC PLATE

As a step in the analysis of the effects of change in illumination, the colors in A.O. plate #5 were matched with Munsell colors. The plate was cut up and the individual dots matched directly. The matches were then calculated by extrapolation from the known x-y coordinates on the ICI system for the standard colors under different illumination. This procedure gives a fair approximation, although it is not precisely accurate.

There are 10 colors in this plate which fall naturally into four groups. These are presented in Table I.

For the normal, the figure is seen as composed of purplish red (group III) and Orange (group IV), with the background as Green (group I) and Blue-green (Group II). For the color blind, the figure is purplish red (group III) and Blue-green (group II), with the Orange (group IV) and the Green (group I) looking so alike as to form the background. As can be seen from the plot in Figure 2, these colors form a figure similar to that in Diagram 6, and the resulting differ-- ence between the normal and the deviant responses follows from that explanation. Figure 2 also has the plot for these colors under a 100-watt incandescent light. The distortion is apparent, but the shift of the colors toward the protanomalous line of confusion is less so, since this plot tends to minimize the difference between the two. Figure 3 is a portion of ICI diagram of the same colors, with the protanope and deuteranope confusion lines drawn through the light red points under the two illuminations to bring out the relationship. The protanope and deuteranope confusion lines under standard day- light fall on either side, which shows that the association is equally difficult for both types. Under 100-watt Mazda, however, the protan- ope confusion line is much removed. This shows why the change from daylight to yellower illumination aids the deuteranope much more than the protanope. Mild protanopes will improve also be- cause the shift in the differences between the colors as shown by the distortion of the shape is stronger for them than the shift in direction of confusion colors.

Figure 2

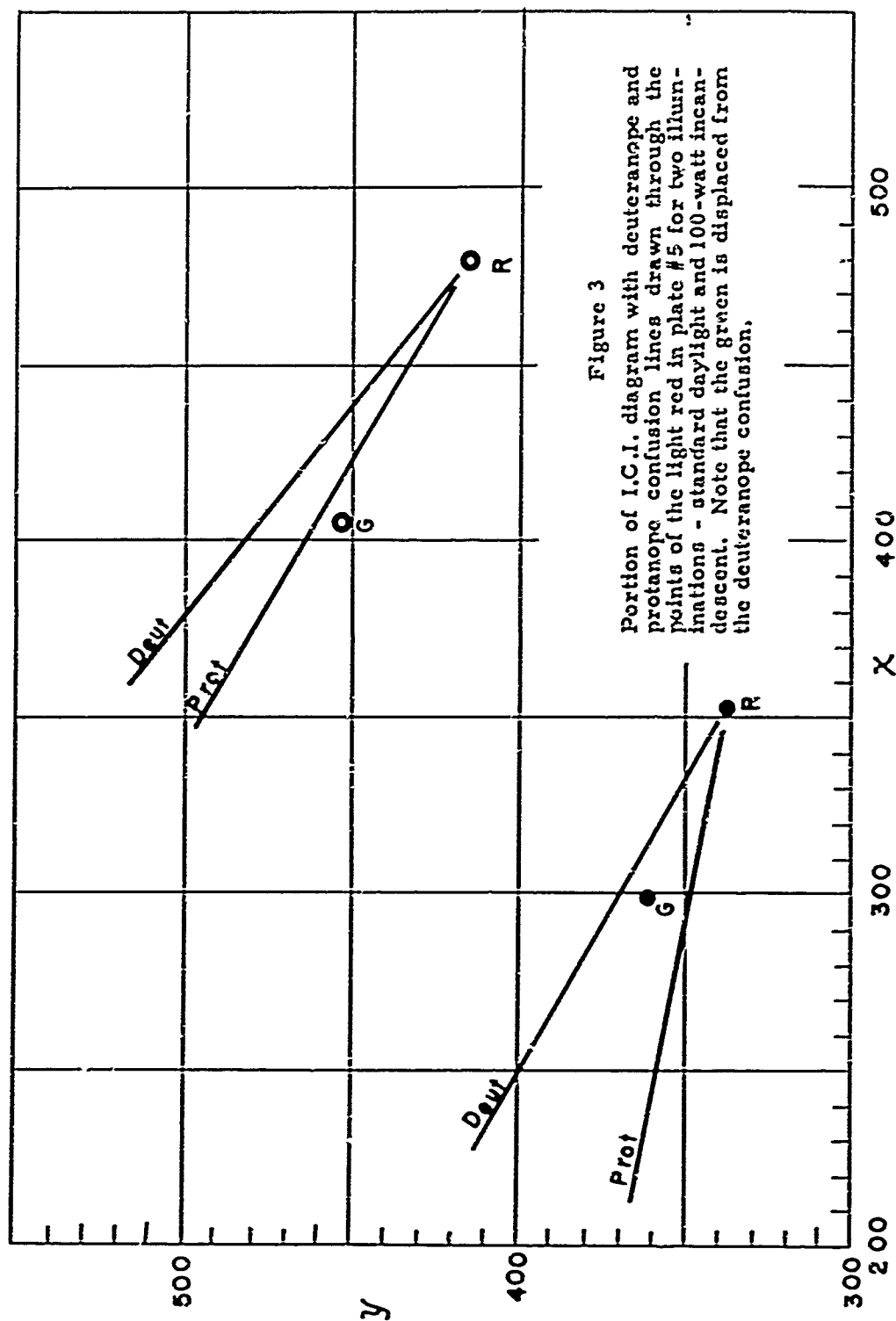PLOT OF A.O. PLATE #5 UNDER
TWO ILLUMINANTS

Figure 3

Portion of I.C.I. diagram with deuteranope and protanope confusion lines drawn through the points of the light red in plate #5 for two illuminations - standard daylight and 100-watt incandescent. Note that the green is displaced from the deuteranope confusion.

Group	Appearance	Munsell Colors	C x	C y	A x	A y
I	Dark Green	6GY 6.3/5.5	351	436	460	468
	Medium Green	5.5GY 5.4/6.2	361	453	458	478
	Light Green	YGY 7.8/6	379	424	482	451
II	Dark Blue Green	3.5G 5.8/4	299	362	403	453
	Light Blue Green	9GY 7.7/3.8	313	366	441	441
III	Dark Purplish Red	5.2YR 7.8/4.2	366	345	496	408
	Light Purplish Red	YRY 9/4	351	346	480	415
IV	Dark Orange	YR 7.8	443	382	545	404
	Medium Orange	7.2YR 7.8/6.4	411	376	525	408
	Light Orange	2Y 8.5/5.5	372	372	493	419

Table I. Matches of A.O. Plate #5 with Munsell colors under Illuminant C. The I.C.I. coordinates for these Munsell colors under C and A are then extrapolated.

References

1. "A Survey of Methods Used in Administering Pseudo-isochromatic Test Plates for Color Vision." Medical Research Laboratory, New London, Conn., Color Vision Report #3, 6 November 1943.

2. "The Effects of Certain Illuminants on Scores made on Pseudo-isochromatic Tests." Medical Research Laboratory, New London, Conn., Color Vision Report #4, 22 November 1943.

3. Munsell Book of Color, The Munsell Color Company, Baltimore, 1929.